# THE ROLE OF SHRUB ROOTS IN SUPPLYING SOIL WITH ORGANIC MATTER AND NITROGEN

P. P. POKHITON, Botanical Gardens, Ukrainian Academy of Sciences, Kiev

Systematic study of the organic matter in soil was started by Kostychev (8), who laid a basis for the biological trend in soil science. This line of research was successfully continued by Krakov (9), who studied mainly the decay processes of plant residues in the soil and the part played by dead organic litter-fall in soil formation. He established that the accumulation of humus in the soil and its composition depend on the amount and quality of the plant residues reaching the soil and on the properties of the mineral part of the soil.

Tyurin (21), investigating forest soils, established that secondary forms of organic soil matter are due mainly to plant-root residues. He regards the role of surface litter as subsidiary and insignificant; while it plays an undoubted part in forming the upper soil horizon of the forest, it is much less important in the process of humus formation in the mineral horizons.

Subsequent research showed that some soils occupied by forest plantations are distinguished by a high organic matter content (4, 5, 6, 12, 13, 14, 15, 16, 17, 20). Interesting experimental work in this direction has been done by Zonn (6), Orlov (11), and Mina (10); these workers established the accumulation of organic residues over a definite period of time and determined the contents of ash element and nitrogen in soil under forest. They did not, however, adduce data on the humus accumulation in soil as a result of the influence of tree root vegetation.

Our investigations were made on material from the Botanical Gardens of the Ukrainian Academy of Sciences in 1957 and 1958. The general geomorphological, soil, and climatic conditions of the Botanical Gardens have been described in detail in papers by Vernander (1), and Shiman (22), and we need only mention that the shrubs selected for study grow in certain parts of the Botanical-Geographical "Ukrainian Lowland Forest" group. The shrubs grow in groups and their growth is not noticeably influenced by vegetation at other levels. The age of the shrubs varies from 8 to 14 years.

Soil samples for analysis were taken at the same time as monoliths with a 0.5 x 0.5 m section for determining root content in them. Five samples were taken from each profile: two from the 20-30 cm soil layer (one in the root zone, the other outside it), two from the 60-70 cm layer, and one from the 0-10 cm layer. We regarded the latter as having been taken from the root zone since the top soil layer is so saturated with roots that it was impossible to take a sample of it outside the root zone. The soil samples taken outside the root zone were used as controls. Special care was taken in preparing the soil samples for analysis, to get a complete selection of plant residues.

The following values were determined: humus content (Tyurin method), water-soluble organic matter (Kubelyu-Timan), total nitrogen (Kjeldahl), and protein nitrogen (Bernstein).

The data shown in Table 1 point to a marked increase in humus content in the root zone of soil under shrub vegetation. The quantity of extra humus content depends both on the shrub species and on the soil.

As an example of how the shrub species influences the organic matter content in the soil we may take the red dogwood and common buckthorn, which grow close together in the same soil. Both shrubs develop a thick root system but the buckthorn has smaller roots: 1360 g/m² of small buckthorn roots were measured in the 90 cm layer against 478 g/m² of dogwood roots, a difference of nearly two-thirds. One would therefore expect the humus increment in the root zone of the soil under buckthorn to be correspondingly higher than that in the soil under dogwood.

The analysis data show, however, that the humus increment in the 20-30 cm layer under dogwood was very high—133.5%, against only 18.0% in the soil under buckthorn. The relatively small humus increment in the buckthorn root zone can be explained by the higher humus content in the soil outside the root zone (2.05%-2.64%), as compared with the same zone under dogwood (1.55%-0.46%). The high humus content in the soil under buckthorn is a result of the intensive root development there and the considerable saturation of the soil with roots.

The direct connection between the amount of humus increment in the root zone soil and its root-saturation can be illustrated by the values for humus content in soil under European cranberry bush and common barberry, growing side by side in the same type of soil. The cranberry

Table 1

Influence of shrub roots on humus content in soil[a]

| Shrub | Soil | Depth, cm | Humus, % | | | |
|---|---|---|---|---|---|---|
| | | | in root zone | outside root zone | difference | humus increment in root zone |
| Dogwood | Podzolic sandy loam developed on old alluvial deposits | 0—10 | 4,60 | — | — | — |
| | | 20—30 | 3,62 | 1,55 | 2,07 | 133,5 |
| | | 60—70 | 0,66 | 0,46 | 0,20 | 43,5 |
| Common buckthorn | Podzolic sandy loam developed on old alluvial deposits | 0—10 | 3,08 | — | — | — |
| | | 20—30 | 2,42 | 2,05 | 0,37 | 18,0 |
| | | 60—70 | 3,09 | 2,64 | 0,45 | 17,0 |
| Tatar honeysuckle | Light grey forest eroded soil developed on loess | 0—10 | 3,62 | — | — | — |
| | | 20—30 | 2,28 | 1,38 | 0,90 | 65,2 |
| | | 60—70 | 0,70 | 0,21 | 0,49 | 233,3 |
| Cornelian cherry | Light grey forest soil over buried soil | 0—10 | 2,70 | — | — | — |
| | | 20—30 | 1,73 | 1,18 | 0,55 | 46,6 |
| | | 60—70 | 0,82 | 0,69 | 0,13 | 18,8 |
| Cherry plum | Grey forest soil developed on loess | 0—10 | 4,60 | — | — | — |
| | | 20—30 | 2,27 | 1,40 | 0,87 | 62,1 |
| | | 60—70 | 0,64 | 0,52 | 0,12 | 23,1 |
| Mock orange | Grey forest soil developed on loess | 0—10 | 3,89 | — | — | — |
| | | 20—30 | 3,21 | 2,68 | 0,53 | 19,8 |
| | | 60—70 | 1,76 | 0,83 | 0,93 | 112,1 |
| Ninebark | Grey forest soil developed on loess | 0—10 | 3,06 | — | — | — |
| | | 20—30 | 2,27 | 2,09 | 0,18 | 8,6 |
| | | 60—70 | — | 1,07 | — | — |
| Rose | Grey forest soil developed on loess | 0—10 | 2,91 | — | — | — |
| | | 20—30 | 2,59 | 1,60 | 0,99 | 61,9 |
| | | 60—70 | 0,84 | 0,67 | 0,17 | 25,4 |
| Privet | Grey forest soil developed on loess | 0—10 | 2,78 | — | — | — |
| | | 20—30 | 2,12 | 0,98 | 1,14 | 116,3 |
| | | 60—70 | 0,92 | 0,52 | 0,40 | 76,9 |
| Blackthorn | Sod-clay developed on clay | 0—10 | 6,79 | — | — | — |
| | | 20—30 | 5,50 | 4,45 | 4,05 | 16,9 |
| | | 60—70 | Not det'd. | | | |
| Single-seed hawthorn | Sod-podzolic sandy loam developed on alluvial-deluvial deposits | 0—10 | 4,98 | — | — | — |
| | | 20—30 | 4,62 | 4,05 | 0,75 | 14,1 |
| | | 120—130 | 1,56 | 1,56 | 0,00 | 0,00 |
| Common barberry | Transitional from eroded leached chernozem to dark-grey forest eroded | 0—10 | 2,38 | — | — | — |
| | | 20—30 | 1,21 | 1,00 | 0,21 | 21,0 |
| | | 60—70 | 1,00 | 0,73 | 0,27 | 37,0 |
| European cranberry bush | Transitional from eroded leached chernozem to dark-grey forest eroded | 0—10 | 2,27 | — | — | — |
| | | 20—30 | 2,33 | 1,08 | 1,25 | 115,7 |
| | | 60—70 | 0,80 | 0,59 | 0,21 | 35,6 |

[a]All analyses were made by the author in the soil entomology laboratory of the Institute of Plant Protection, Ukrainian Academy of Agriculture, which was kindly put at his disposal.

Note: Comma represents decimal point.

Table 2

Influence of plant roots on content of water soluble organic matter in the soil

| Shrub | Soil | Depth, cm | Water-soluble organic matter mg C/100 g soil | | | |
|---|---|---|---|---|---|---|
| | | | in root zone | outside root zone | difference | humus increment in root zone |
| Dogwood | Podzolic sandy loam | 0—10 | 35,10 | — | — | — |
| | | 20—30 | 35,10 | 28,08 | 7,08 | 25,0 |
| | | 60—70 | 19,20 | 8,64 | 10,57 | 122,3 |
| Common buckthorn | Podzolic sandy loam | 0—10 | 42,16 | — | — | — |
| | | 20—30 | 33,36 | 29,84 | 3,52 | 11,8 |
| | | 60—70 | 31,60 | 28,08 | 3,53 | 12,6 |
| Tatar honeysuckle | Light grey forest | 0—10 | 35,04 | — | — | — |
| | | 20—30 | 36,88 | 26,32 | 10,56 | 40,1 |
| | | 60—70 | 17,44 | 10,40 | 7,04 | 67,7 |
| Cornelian cherry | Light grey forest | 0—10 | 36,88 | — | — | — |
| | | 20—30 | 26,32 | 19,20 | 7,12 | 37,1 |
| | | 60—70 | 13,92 | 8,64 | 5,28 | 62,3 |
| Cherry plum | Grey forest | 0—10 | 38,64 | — | — | — |
| | | 20—30 | 28,08 | 21,12 | 6,96 | 33,0 |
| | | 60—70 | 13,92 | 10,40 | 3,52 | 33,8 |
| Mock orange | Grey forest | 0—10 | 36,88 | — | — | — |
| | | 20—30 | 40,40 | 36,88 | 3,52 | 9,3 |
| | | 60—70 | 21,04 | 12,16 | 8,88 | 73,1 |
| Ninebark | Grey forest | 0—10 | 31,60 | — | — | — |
| | | 20—30 | 23,56 | 19,28 | 4,28 | 22,2 |
| | | 60—70 | — | 15,68 | — | — |
| Rose | Grey forest | 0—10 | 36,88 | — | — | — |
| | | 20—30 | 29,84 | 23,76 | 6,08 | 25,6 |
| | | 60—70 | 12,16 | 10,40 | 1,76 | 17,0 |
| Privet | Grey forest | 0—10 | 22,80 | — | — | — |
| | | 20—30 | 21,04 | 19,20 | 1,84 | 9,6 |
| | | 60—70 | 8,64 | 6,88 | 1,76 | 25,6 |
| Blackthorn | Sod clay | 0—10 | 82,65 | — | — | — |
| | | 20—30 | 65,04 | 58,00 | 7,04 | 12,1 |
| | | 60—70 | Not det'd. | | | |
| Single-seed hawthorn | Sod podzolic sandy loam | 0—10 | 38,64 | — | — | — |
| | | 20—30 | 35,10 | 29,84 | 5,26 | 17,6 |
| | | 120—130 | 26,32 | 18,20 | 8,12 | 44,7 |
| Common barberry | Transition from eroded leached chernozem to dark-grey forest eroded | 0—10 | 26,32 | — | — | — |
| | | 20—30 | 24,50 | 15,68 | 8,88 | 56,0 |
| | | 60—92 | 13,92 | 12,08 | 1,84 | 15,2 |
| European cranberry bush | Transition from eroded leached chernozem to dark grey forest eroded | 0—10 | 28,08 | — | — | — |
| | | 20—30 | 35,10 | 19,28 | 15,82 | 81,5 |
| | | 60—70 | 15,68 | 12,08 | 3,60 | 29,8 |

Note: Comma represents decimal point.

bush, in addition to developing a thick root system (727 g/m² in the 90 cm soil layer) gives a high humus increment in the root zone at a depth of 20-30 cm (115.7%), whereas in the soil under barberry bush, where the root content is low (66 g/m²) the humus increment is found to be

Table 3

Influence of shrubs on nitrogen content in the soil

| Shrub | Soil | Depth, cm | Total nitrogen in percent | | | |
|---|---|---|---|---|---|---|
| | | | in root zone | outside root zone | difference | humus increment in root zone |
| Dogwood | Podzolic sandy loam | 0—10 | 0,217 | — | — | — |
| | | 20—30 | 0,172 | 0,070 | 0,102 | 145,8 |
| | | 60—70 | 0,040 | 0,027 | 0,013 | 48,2 |
| Common buckthorn | Podzolic sandy loam | 0—10 | 0,191 | — | — | — |
| | | 20—30 | 0,140 | 0,124 | 0,016 | 12,9 |
| | | 60—70 | 0,162 | 0,145 | 0,017 | 11,7 |
| Tatar honeysuckle | Light grey forest | 0—10 | 0,211 | — | — | — |
| | | 20—30 | 0,144 | 0,94 | 0,050 | 53,2 |
| | | 60—70 | 0,049 | 0,031 | 0,018 | 58,1 |
| Cornelian cherry | Light grey forest | 0—10 | 0,153 | — | — | — |
| | | 20—30 | 0,101 | 0,062 | 0,039 | 63,0 |
| | | 60—70 | 0,051 | 0,036 | 0,015 | 41,7 |
| Cherry plum | Grey forest | 0—10 | 0,204 | — | — | — |
| | | 20—30 | 0,132 | 0,085 | 0,047 | 55,3 |
| | | 60—70 | 0,043 | 0,03 | 0,004 | 10,3 |
| Mock orange | Grey forest | 0—10 | 0,211 | — | — | — |
| | | 20—30 | 0,176 | 0,141 | 0,035 | 24 8 |
| | | 60—70 | 0,110 | 0,048 | 0,062 | 129,0 |
| Ninebark | Grey forest | 0—10 | 0,157 | — | — | — |
| | | 20—30 | 0,122 | 0,116 | 0,006 | 5,2 |
| | | 60—70 | — | 0,06 | — | — |
| Rose | Grey forest | 0—10 | 0,169 | — | — | — |
| | | 20—30 | 0,169 | 0,077 | 0,096 | 124,7 |
| | | 60—70 | 0,056 | 0,045 | 0,011 | 24,5 |
| Privet | Grey forest | 0—10 | 0,155 | — | — | — |
| | | 20—30 | 0,115 | 0,049 | 0,066 | 134,7 |
| | | 60—70 | 0,043 | 0,017 | 0,026 | 153,0 |
| Blackthorn | Sod clay | 0—10 | 0,408 | — | — | — |
| | | 20—30 | 0,329 | 0,240 | 0,089 | 37,1 |
| | | 60—70 | Not det'd. | | | |
| Single-seed hawthorn | Sod podzolic sandy loam | 0—10 | 0,232 | — | — | — |
| | | 20—30 | 0,247 | 0,201 | 0,046 | 22,9 |
| | | 120—130 | 0,067 | 0,063 | 0,004 | 6,4 |
| Common barberry | Transition from eroded leached chernozem to dark-grey forest eroded | 0—10 | 0,144 | — | — | — |
| | | 20—30 | 0,076 | 0,057 | 0,019 | 33,4 |
| | | 60—70 | 0,060 | 0,048 | 0,012 | 25,0 |
| European cranberry bush | Transition from eroded leached chernozem to dark-grey forest eroded | 0—10 | 0,179 | — | — | — |
| | | 20—30 | 0,142 | 0,069 | 0,073 | 105,8 |
| | | 60—70 | 0,048 | 0,042 | 0,006 | 14,3 |

Note: Comma represents decimal point.

low too (21.0%).

At a depth of 60-70 cm the humus increment in the root zone soil under cranberry is 35.6%, against 37.0% under barberry. The similarity between the two values, despite differences in the root saturation of the soil under the two different shrubs, apparently is due to the influence of other biotic factors, in particular the activity of earthworms (2, 3, 7).

It is not open to question that humus accumulation in the root zone of soil is due to the activity of plants. The humus source may be decaying root hairs, feeding roots and to some extent vascular roots, as Orlov has shown (11). Another important humus source is organic and organic-mineral matter secreted into the soil by live roots, as we can see from the values for water-soluble organic matter given in Table 2, which show that the soil in the shrub zone contains more of this than the soil outside the root zone.

No clear relationship can be detected between the amount of the increment in water-soluble organic matter, and the shrub species and root-saturation of the soil, or the total amount of humus increment (Tables 1 and 2). The highest percentage increment of water-soluble organic matter in the root zone soil was found under shrubs growing in soil transitional between eroded leached chernozem and dark-grey forest soil on loess (cranberry, barberry) and the lowest percentage increment in the soil under shrubs in podzolic sandy loam on fluvioglacial deposits (dogwood, buckthorn), grey forest soil on loess (ninebark, rose, privet) and sod-clay soil on clays (blackthorn).

The considerable range and variation of water soluble humus content in soils must be due to the presence, in the plant root zone, of large masses of microorganisms which use the organic soil matter as energy material for their own activity. This conclusion is based on the findings of Samtsevich and Katerinich (18, 19) who established that root secretions amounting in all to 5%-10% of the root weight are continuously taken up by microorganisms in the rhizosphere.

The values for total nitrogen content (Table 3) can be taken as indicating the active influence of shrub root systems on the soil.

The greatest nitrogen increment in the root zone in the 20-30 cm soil layer occurs under red dogwood (145.8%), European cranberry (105.8%), and Cornelian cherry (63.0%). Under other shrubs (cherry plum, blackthorn, barberry) the nitrogen increment in the root zone is smaller (55.3%-22.9%) and sometimes (buckthorn, ninebark) very small (12.9%-5.2%).

In the 60-70 cm layer considerable nitrogen increment has been found in the root zone under privet (153.0%), mock-orange (129.0%), honeysuckle (58.1%), and dogwood (48.2%). In soil under shrubs the nitrogen increment in the root zone varies at this depth from 41.7% under Cornelian cherry to 6.4% under hawthorn.

Sources of nitrogen in the soil are organic matter from plant residues and soil microorganisms and invertebrates in the root zone.

The data on soil humus and nitrogen content in the root zone under shrubs justify the conclusion that living organisms play an immense part in the soil formation process and in enhancing the potential fertility of the soil. Plants, microorganisms and soil invertebrates accumulate and retain in their bodies large amounts of ash element and nitrogen, protecting them from being dissolved and leached into the deep layers of the soil and into the soil-forming parent material outside the main plant root zone.

These elements are only gradually released from the dead plant residues and the bodies of the organisms. A part, however, consisting of products of the roots' activity, continuously fill up the soil with nutrients in a form available to plants.

## Conclusions

1. Shrub vegetation actively causes organic matter and nitrogen to accumulate in the root-zone soil. The amount of accumulation depends on the shrub species and on the saturation of the soil with roots, as well as on the soil type.

2. The humus increment in the root zone sharply increases under shrubs which provide maximum saturation of the soil with small roots. The highest percentage of humus increment is observed in podzolic sandy loam and the lowest sod-podzolic sandy loam and dark grey forest soils.

3. In soil under shrubs, dying roots as well as the roots of herbaceous vegetation penetrating the soil under the shrub canopy, and also the surface litter-fall, can be sources of organic matter. Root secretions also seem to be of great importance.

4. No clear relationship has been detected between the increase in the content of water-soluble organic matter in the root zone of soil under shrubs and the shrub species and saturation of the soil with roots.

5. Nitrogen accumulation in the shrub root zone of soils occurs primarily in protein form. Humic substances, organic and mineral root secretions and soil microorganisms and invertebrates can be sources of nitrogen in soil under shrubs.

6. The possibility of enriching the soil with organic material and nitrogen by an appropriate selection of shrub vegetation and by adjusting the composition of existing shrub plantations opens up new opportunities for enhancing the yield of plantations for industrial and special purposes such as soil and field protection, melioration, water conservation, decoration and display.

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